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FINAL REPORT

SOLAR MAGNETIC FIELDS

Sara F. Smith
Contract No. N00014-66 C0058
ARPA Order 215, Amend. No. 21

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"SOLAR MAGNETIC FIELDS"

ARPA Order 215, Amend. No. 21

Contract Number N00014-66-C0058

Period Covered: 29 Nov. 1965 - 28 Nov. 1966

LR-20445   December 1966

Sara F. Smith

Lockheed Solar Observatory

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TABLE OF CONTENTS

FOREWORD

This report describes the results of research on "Solar Magnetic Fields" accomplished under Contract N00014-66-C0058 with the Office of Naval ..search. The funds were provided by the Advanced Research Projects Agency. The contract was awarded for the correlation of magnetic field changes with chromospheric phenomena using empirical and statistical methods. This project was an extension of work initiated under the previous Contract, Nonr-3933(00), "Research on Solar Magnetic Fields". The work described in the present report was accomplished between 21 March 1966 and 30 November 1966.

Other reports submitted under this contract were:

Quarterly Letter Reports

Number 1	5 May 1966
Number 2	8 July 1966
Number 3	12 October 1966

Quarterly Technical Reports

Number 1	18 May 1966
Number 2	28 July 1966
Number 3	8 November 1966

A paper has been prepared for publication combining some of the results of work completed under this contract, N00014-66-C0058, and the previous contract, Nonr-3933(00). This paper, "Flare Positions Relative to Photospheric Magnetic Fields", will be submitted to the new journal, Solar Physics. The basic contents of this paper were presented in two parts at the 118th and 121st Meetings of the American Astronomical Society. The first presentation, entitled "Some Characteristic

Properties of Solar Magnetic Fields", was given in Lexington, Kentucky, 15-17 March 1965. The second presentation, "An Active Center and Its Magnetic Field", was given in Hampton, Virginia, 28-31 March 1966.

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ACKNOWLEDGEMENTS

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ILLUSTRATIONS

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Section 1

INTRODUCTION

A study was conducted of the correspondence of photospheric magnetic fields with structures and transient phenomena observed in the chromosphere. The primary data used were isogauss maps constructed from the Mt. Wilson daily, full disk magnetograms for the period 1959 through 1962, and three fine-scan magnetograms made on 6 July 1965. The H-alpha comparisons were made with the Lockheed H-alpha filtergrams. Supplementary data used were H-alpha and calcium films of the sun containing one Mt. Wilson spectroheliogram per day for the period July 1959 through December 1964.

Most of the data reduction was performed under the previous contractual study for research on solar magnetic fields, (Smith and Howard, 1965). In the present document are reported the additional results obtained during the one year extension of this project. The first section describes in detail the correspondence between the fine-scan magnetograms and the high resolution filtergrams obtained on 6 July 1965. The second and third sections are largely statistical information about magnetic regions and their relationship to the occurrence of major flares.

1

Section 2

AN ACTIVE CENTER AND ITS MAGNETIC FIELD

Only one large active center was present on the solar disk on 6 July 1965. Three fine-scan magnetograms of this active center were obtained by J. W. Harvey at the Mt. Wilson Observatory. A period of approximately fifteen minutes was required to obtain each complete magnetogram of the region at 10 sec. of arc resolution. The starting times of the magnetograms were 1615, 1645, and 2355 U.T. The third fine-scan magnetogram was taken while a flare of importance 1 was in progress from 2306 to 2523 U.T. Mean longitudinal field strengths of 3, 6, 9, 12, 25, 40, and 60 gauss for each polarity were recorded in a color coded form by two pen recorders containing red and green ink. For this study, isogauss maps were constructed from the original pen recorded magnetograms. The magnetogram taken at 1645 U.T. is shown in the form of isogauss contours in the left side of Figure 1. Only isogauss contours of mean magnetic field strengths of 9, 25 and 60 gauss are included. The solid and dashed lines respectively represent the areas of positive and negative polarity.

High resolution H-alpha filtergrams of this active region were recorded at 15 second intervals from 1545 to 2559 U.T. Atmospheric degradation of the images limited the resolution of the filtergrams to approximately one second of arc on 6 July 1965. The H-alpha filtergram recorded at 1645 is shown in the right side of Figure 1. Comparison of the magnetogram and H-alpha filtergram in Figure 1 reveals an organized pattern of fibril structures corresponding to almost every area of magnetic field equal to or greater than three

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6 JULY 1965 – 1645 U.T.

H-ALPHA FILTERGRAM

MAGNETOGRAM

Figure 1. Comparison of a photospheric magnetogram with a chromospheric H-alpha filtergram of 2.5 A bandpass in the negative. From outer to inner, the isogauss lines of the magnetogram represent mean magnetic field strengths of 9, 25, and 60 gauss for the longitudinal component of the field. Solid and dashed lines are used to show the positive and negative polarities respectively.

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3

gauss. A semi-quantitative correlation between magnetic field strength and H-alpha structures was achieved by superpositioning filtergrams over the isogauss maps. Accurate superpositioning was easily obtained by aligning the areas of weak field surrounding the active region with their obvious corresponding H-alpha structures. The accuracy of the superpositioning was limited only by the resolution of the magnetograms and is estimated to be reliable within ten seconds of arc.

The size, shape, and intensity of the H-alpha fine structures are all excellent indications of the approximate strength of the longitudinal component of the magnetic field. The inter-relationships of these parameters and their correlation to the field strength of the longitudinal component are presented in Table I.

Using these and other fine-scan magnetograms displaying the longitudinal component of the field, Schmidt and Harvey (1966) have derived the transverse and total fields and have also compared their results with the fine structures on H-alpha filtergrams.

The correspondence between H-alpha structures and the magnetic field strengths shown in Table I may be partly a function of the resolution of the magnetograms. Precise agreement with these groupings would not necessarily be expected for future observations obtained with magnetographs employing a smaller aperture than 10 seconds of arc on a side. Similarly magnetic field strengths would be expected to increase with increasing magnetograph resolution.

The correlation in Table I does not apply in the region of the neutral line of the longitudinal component of the field. A neutral line is defined as a boundary between an area of positive and negative longitudinal field. This is the line of 0 longitudinal field in a plage.

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TABLE I

| H - A L P H A   S T R U C T U R E S | | | Approximate Range of Longitudinal Field Strengths in Gauss |
Shape and Description	Size in Sec. of Arc	Intensity Relative to 0 Field	
Long Fibrils	10 - 30	less than	3 6
Short Fibrils	5 - 10	same	6 - 12
Fine mottles	5	slightly greater	12 - 40
Bright plage	structure size unresolved at exposure used	appreciably greater	> 40

All active regions are bipolar in their early stages of development and therefore, have at least one neutral line. This region, as is typical of relatively small or young active centers, has only one neutral line. The location of this neutral line is, in part, marked by the presence of fibrils 10-30 seconds of arc in length and, in part, by the existence of two filaments. At present, we define fibrils as absorption structures appearing to follow magnetic lines of force and filaments as absorption features (generally larger than fibrils) which appear to run perpendicular to magnetic lines of force. However, these definitions may not be consistent for chromospheric magnetograms if such were available.

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There are several noteworthy features about the structures associated
with the neutral line in this plage. The long fibril structures do
not appear to be related to strong fields except in the region of the
neutral line. These fibrils appear to run between sunspots of
opposite polarity and to cross the neutral line at approximately right
angles. In the absence of the fibrils, the remainder of the neutral
line within this region is marked by the presence of filaments. In
these observations both filaments and fibrils do not occur at one
location.

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The Development of a Major Flare

An importance 1 flare occurred in the region described above at 2306:00 U.T. ± 30 seconds. The flare begins simultaneously at two points of positive polarity, one of which is clearly adjacent to the neutral line of the longitudinal magnetic field. Another flare point was initiated one minute later. It also occurred adjacent to the neutral line but in the area of negative polarity. These two flare points on opposite sides of the neutral line rapidly developed into the two longest lived and brightest segments of the flare. The division of the flare into two major segments separated by the neutral line is illustrated in Figure 2. In this illustration a positive photographic copy of the flare is superposed over a negative photographic copy of the active region. Some of the plage has been reproduced at the same intensity as the flare resulting in an apparent oversized representation of the flare. This was done so that the correlation with the isogauss map would become more apparent.

In Figure 3, the sunspot configuration at 2406 U.T. is shown super-posed on a series of H-alpha pictures depicting the development of the flare. The two major flare segments are roughly parallel and extend outside of the ellipse of sunspots. Parts of the flare, how-ever, do occur within the group of sunspots and lie directly over some of the spots. These parts of the flare exhibit very little motion relative to parts of the flare outside of the sunspot group. Velocities in the flare segments within the ellipse of sunspots were less than 9 km. per sec.

The development of the two major parallel flare segments appears to be closely related to the location of the neutral line and to the strength and configuration of the longitudinal magnetic field. As the flare progresses these flare segments rapidly lengthen in

6 JULY 1965 — 2405 U.T.

H-ALPHA FILTERGRAM

MAGNETOGRAM

Figure 2. Comparison of the importance of 1 flare of 6 July 1965 with the isogauss contours of the longitudinal component of a magnetic field in the photosphere. From outer to inner the lines represent mean field strengths of 12, 32, and 78 gauss.

8
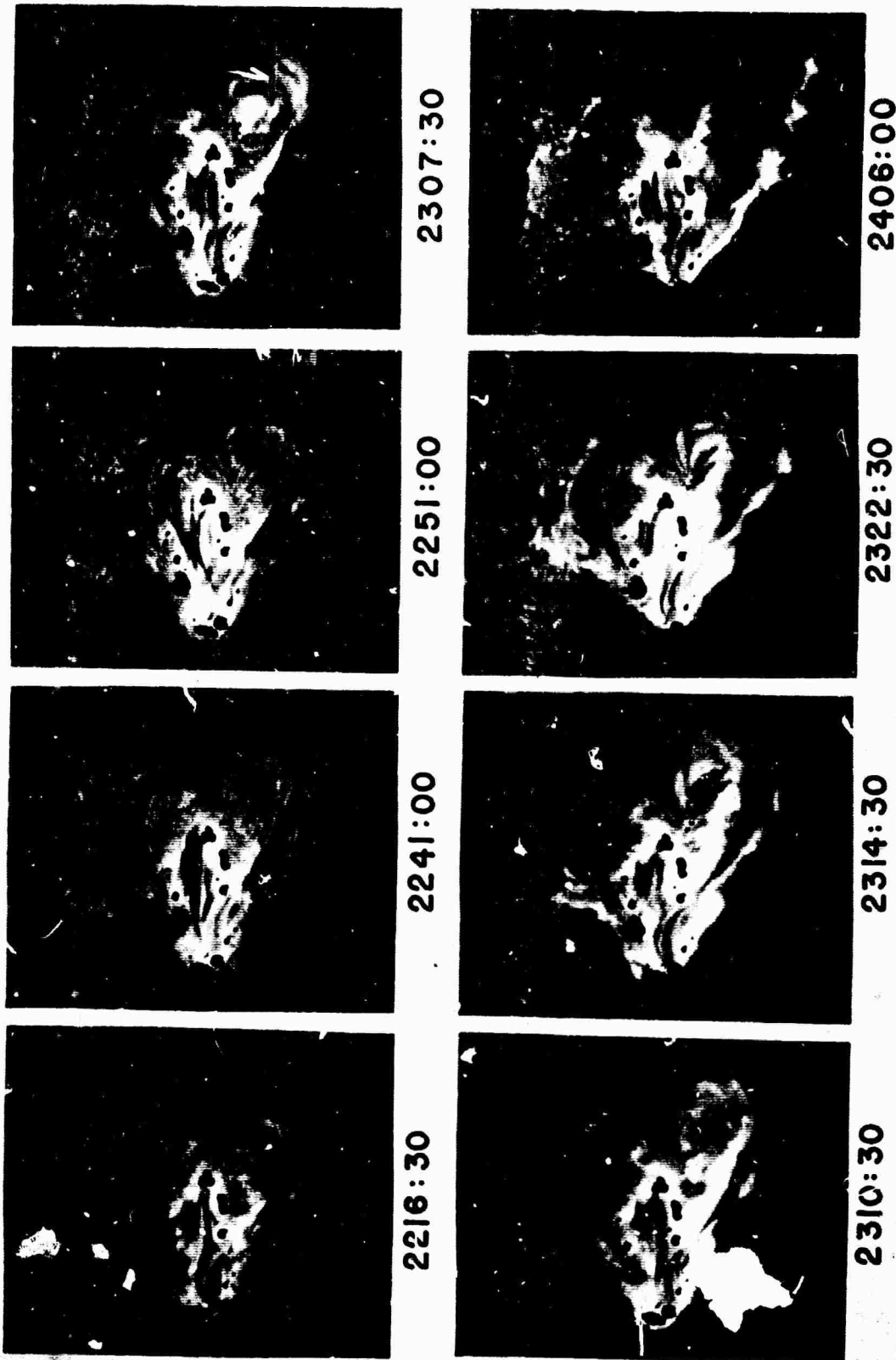
Figure 3. Development of an importance 1 flare on 6 July 1965. The sunspot configuration at 2406 U.T. is superposed on each frame.

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directions approximately parallel to the neutral line and toward areas of weaker field. Simultaneous with the lengthening, these two parallel segments of the flare drift apart in directions approximately perpendicular to the neutral line. The drifting apart of flare segments is a feature which has been noted by Dodson (1949), Dodson and Hedeman (1960).and Valnicek (1961) and which has been discussed in further detail by Svestka (1962) and Malville and Moreton (1965). For the flare on 6 July 1965, the drift was measured at equally spaced positions along the flare segments. Velocities of flare motion were computed at each of these positions for successive intervals of time. The nature of the lateral displacement of these flare segments is graphically illustrated in Figures 4, 5, and 6. In Figure 4, the velocities, computed for three intervals of time, are plotted versus equally spaced positions along the horizontal axis representing the positions along the flare segments at which the velocities were measured. From left to right the field strength generally decreases. It is seen that the rate of lateral displacement increases with decreasing field strength. Also, as the flare progresses, the drift velocity of the flare segment decreases as is shown by the difference in the slopes of the curves in Figure 4. The mean rate of this deceleration is displayed by the curve in Figure 5. This deceleration occurs as the flare segments are displaced laterally in the direction of increasing field strength. That is, the motion begins very close to the neutral line and is directed up the gradient of the longitudinal field. The deceleration in this direction is also shown in Figure 6 where the average velocity, computed from the velocities at equally spaced locations along the flare segments, and the time from flare start are plotted on logarithmic scales. A straight line fitting the points on the graph shows the apparent direct proportionality of these parameters which may be expressed as:

$$\log v = c_1 \log t + c_2$$

where v represents average velocity, t represents time and c_1 and c_2
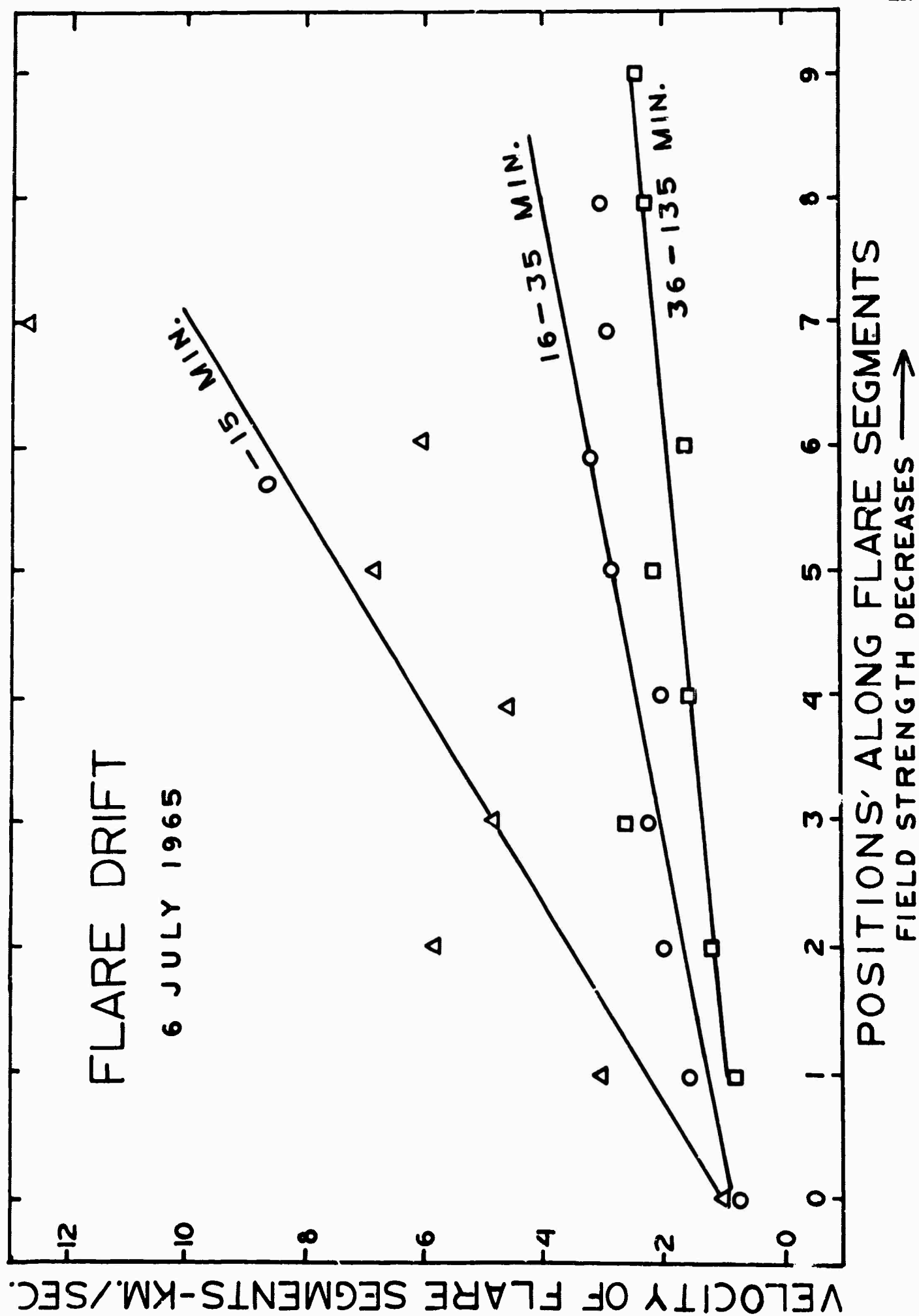
Figure 4. Rate of flare drift perpendicular to the neutral line of the longitudinal magnetic field measured for three intervals of time during the flare.

DECELERATION OF FLARE DRIFT

6 JULY 1965

AVE. VELOCITY IN KM./SEC.

TIME IN MIN. FROM FLARE START
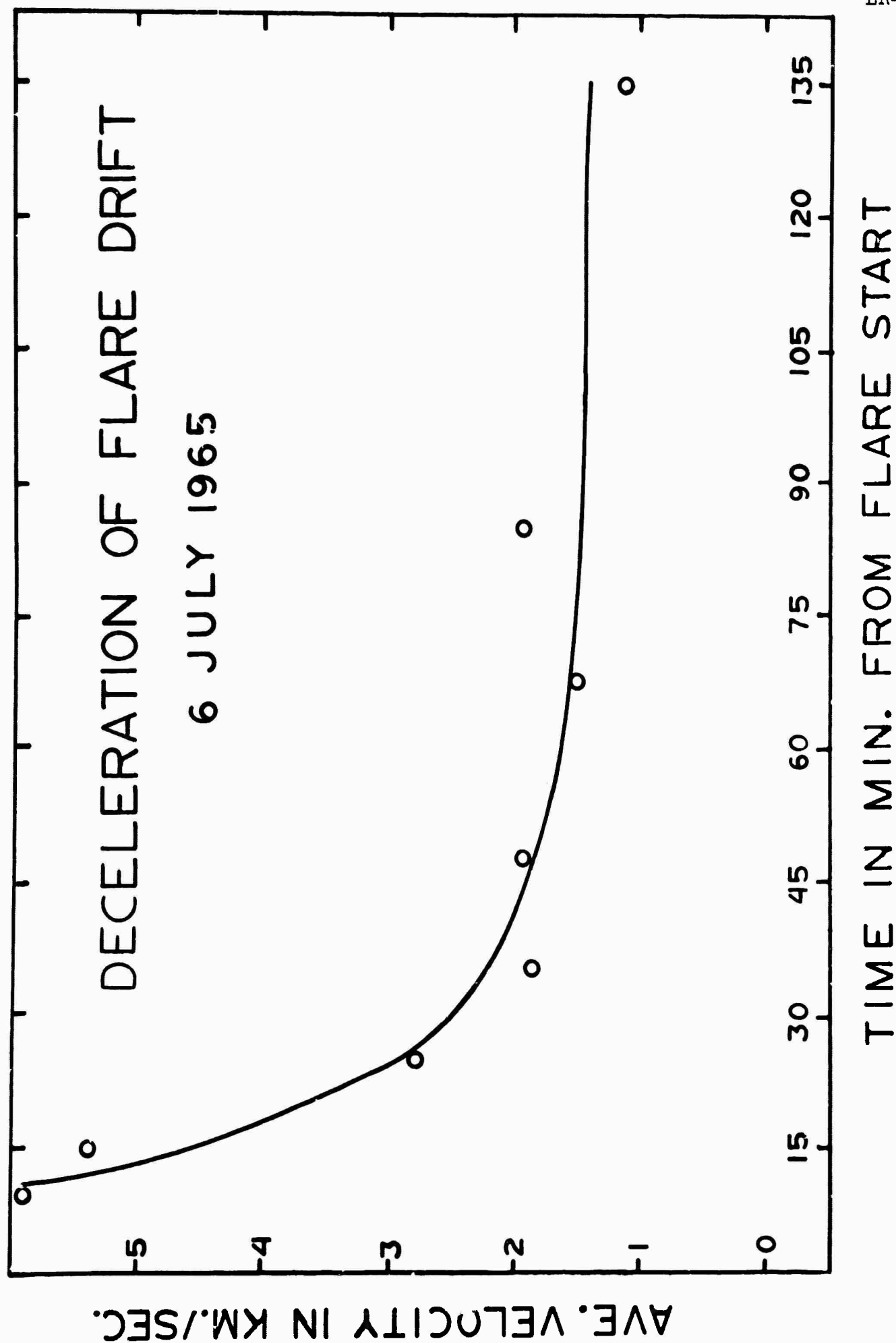
Figure 5. Deceleration of the average flare drift perpendicular to the neutral line of the longitudinal magnetic field.

DECELERATION OF FLARE DRIFT

6 JULY 1965

TIME IN MIN. FROM FLARE START

AVE. VELOCITY IN KM./SEC.
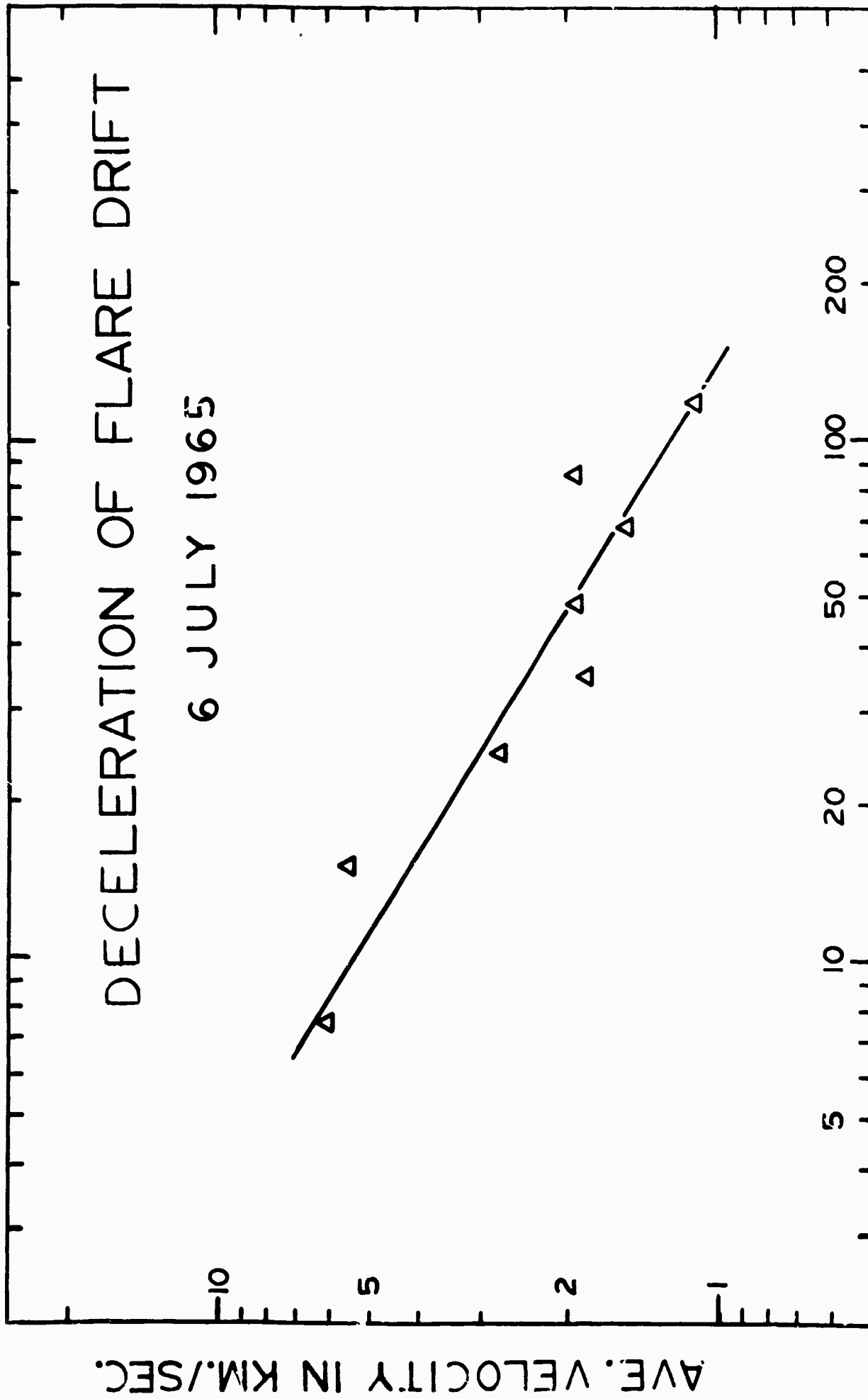
Figure 6. Deceleration of the average flare drift on logarithmic scales.

are constants. Since the motion is directed up the field gradient, it is speculated that c_1 may be a function of the field gradient. Additional data is needed to establish the general applicability of the above equation and to determine the relationship of these parameters to values of magnetic field strength and field gradient. Other motions were exhibited by this flare. Two short-lived transverse components of motion, seen during the first nine minutes of the flare, had a velocity between 51 and 119 km. per sec. This motion was similar to that of the two major flare segments in that the components were initiated almost simultaneously, were approximately parallel, and rapidly drifted apart. The area traversed corresponds to the outer edge of positive polarity. At this location the neutral line and field configuration are not well defined.

At the start of the flare, another point of emission is initiated on the left border of the sunspot ellipse as seen in Figure 3. This small flare segment rapidly develops into a faint, expanding circle of flare emission which persists for only 6 minutes. It is just detectable in frames 2310:30 and 2314:30 U.T. in Figure 3 between the two largest sunspots.

Three mintues after flare start, faint emission began to stream out of a bright region of the flare lying within the sunspot ellipse. This faint emission appeared to follow a curved path. It is seen in the last 3 frames in Figure 3 above the filament and above the ellipse of sunspots. Measures of the distance traversed by this emission for 3 short intervals of time yielded straight-line velocities from 38 to 111 km. per sec. with a mean velocity of 63 km. per sec.

Faint transient emission also occurs prior to the rapid brightening which we define as flare start. This emission is closely related to preflare changes observed in the filament to the lower right of the

sunspot group in the first 3 frames of Figure 3. Some of the absorption material of the filament appears to make a rapid transition to emission 26 minutes before the onset of the flare. The brightest part of this transitory emission is seen prior to flare start in Figure 3. It commences in the total disappearance of the filament within a few minutes of flare start.

The diagram in Figure 7 summarizes the locations and directions of the motions observed in the flare relative to the sunspot configuration at 2406:00 U.T. Table II following Figure 7 identifies the type of flare motions observed, gives their time of occurrence relative to flare start, shows the duration of each motion, and presents the range of velocities measured for each type of motion. Because of the rapid brightening and relatively slow decrease in the intensity of points within the flare segments, the slower motions referred to as flare drift (2 and 5, Table II) are interpreted as progressive excitation rather than material in motion. Since moving knots of preflare and flare associated emission are frequently observed at the limb, the motion of the preflare emission is probably best interpreted as the real motion of matter. However, definite knowledge of the visible counterparts of these types of flare motion at the limb has not been established. In all except the cases of flare drift, more high resolution evidence is needed to differentiate between the cases of progressive excitation and the cases of real material motion.

It is seen in the diagram in Figure 7 that the short-lived motions of the flare outside of the ellipse of sunspots generally exhibit higher velocities than the parts of the flare within and over the spots. This observation is similar to the trends shown in Figures 4, 5, and 6. High lateral velocities in flare segments occur in areas of relatively weak longitudinal field and conversely, low velocities are associated with relatively strong longitudinal field. Also, the

FLARE MOTIONS — 6 JULY 1965
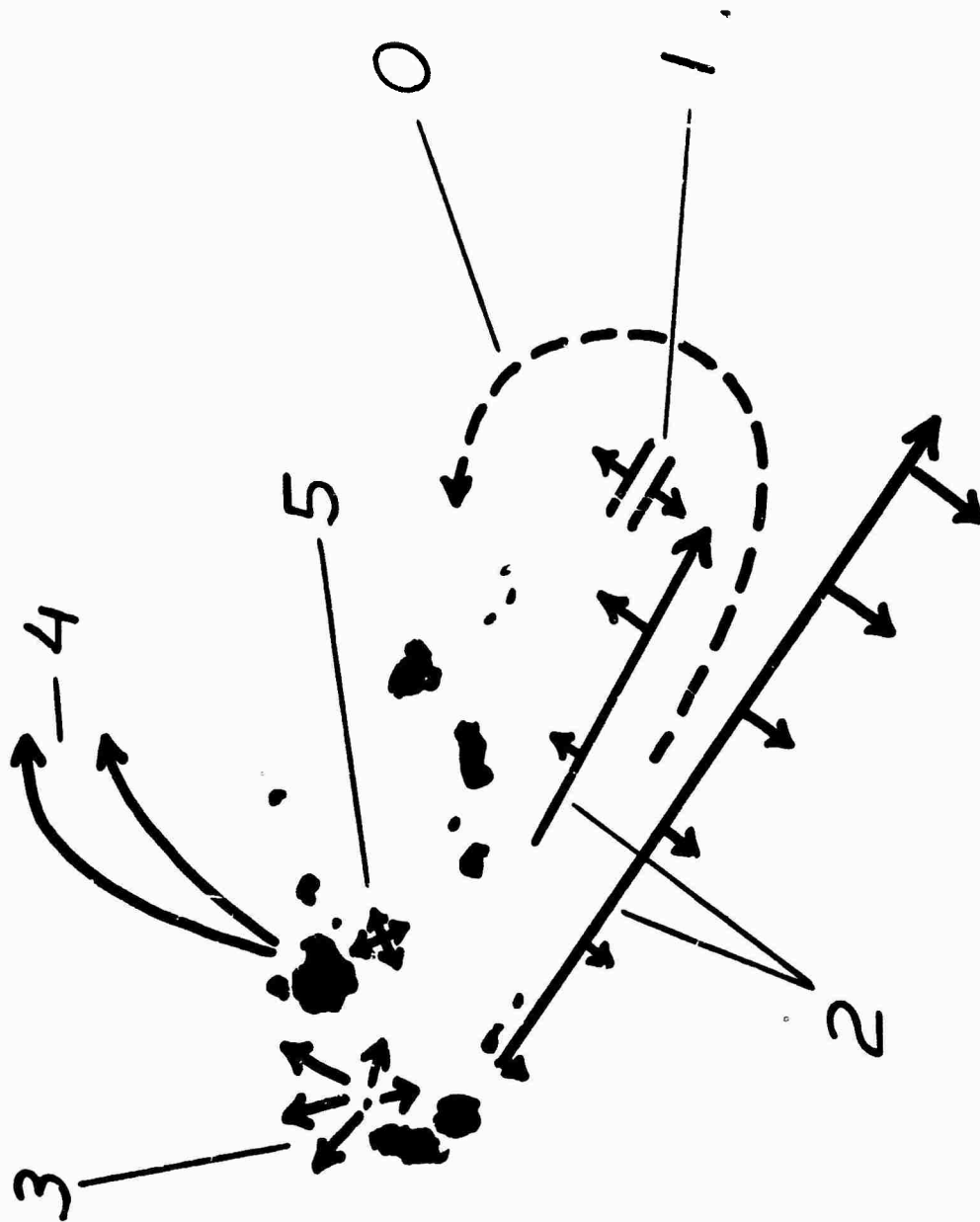
Figure 7. Diagram showing the types of motion exhibited by various segments of the major flare of 6 July 1965.

16

T A B L E   II

D E S C R I P T I O N	Relative Time of Occurrence in Minutes Flare Start = 0	Duration in Minutes	Range of Velocities in km./sec.
0 Preflare Emission	-26—2	28	-
1 Initial Rapidly-Moving Faint Emission	0—3	3	51 - 119
2 Drift of Major Flare Segments	0—80	80	1 - 13
3 Small Flare Segment on Border of Spots	0—6	6	22 - 34
4 Faint Emission Extending from Flare	3—19	16	38 - 111
5 Flare Segment within Ellipse of Sunspots	3—17	14	0 - 9

faster motions occurred during the first few minutes of the flare and tended to be faint.

In regard to the directions of motion, two characteristics were noted. First, no motion was directed across a neutral line. Each motion was confined to a single polarity, with the possible exception of the pre-flare transition to emission in the filament. In this situation the emission appears to travel along the path of the filament. Secondly, motions in the flare segments were observed both along and across iso-gauss contours. In particular, motions in the two major flare segments were noted both parallel and perpendicular to the neutral line.

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17

Section 3

DISTRIBUTIONS OF MAGNETIC REGIONS

3.1 Classifications of Solar Magnetic Fields

The primary data under study consists of 2128 magnetic regions identified on the sun between 1 August 1959 and 30 December 1962. These regions are not all independent, separate entities. The regions are identified for each solar rotation and assigned new region numbers even if the same regions appeared on the previous rotation.

The classification of regions was originally intended to parallel the Mt. Wilson system for classifying sunspots into basic unipolar (α), bipolar (β), and multipolar (γ) units. Correspondingly the magnetic regions were classed basically as A, B or Y. However, the magnetic regions warranted further refinements of classification and the following system was developed to apply only to magnetic regions.

> AP - unipolar region, positive polarity
>
> AN - unipolar region, negative polarity
>
> B - bipolar region
>
> BY - bipolar region with peninsulas of one polarity extending into the opposite polarity
>
> BS - bipolar region containing an isolated area of opposite polarity within either the positive or negative component
>
> BYS - a region which could be defined as both a BY and a BS region
>
> Y - multipolar region
>
> X - classification unknown

RB   Classifications as above except the bipolar

RBY   (B) components are reversed from the normal

RBS   configuration for either the northern or

RBYS   southern hemisphere of the sun.

3.2 Comparison of Magnetic Region and Sunspot Group Classifications

The distribution of magnetic regions according to the above classifications is given in Table III. For comparison the corresponding distribution of sunspot groups according to the Mt. Wilson classification system is also presented.

Because of the large number of regions of unknown classification (X), the relative number of regions in each classification in Table III are only approximate. However, two outstanding characteristics appear. First, the total number of unipolar regions (AP and AN) on the sun during this period is approximately equal to the number of bipolar (B) regions. In this context it should be reiterated that unipolar regions are the remnants of one polarity of one or more old bipolar regions (Smith and Howard, 1965). Secondly, complex magnetic regions (BY, BS, BYS, and Y) and all reversed polarity regions are relatively rare.

The correspondence between sunspot classifications and magnetic region classifications is only approximate. Although the associations between sunspot group and magnetic region classifications presented in Table III are expected to be those most often observed, other associations are possible. For instance, a bipolar sunspot group could correspond to a magnetic region classed as BY or BS. In general, unipolar sunspots (α + or α -) should be associated with bipolar (B) magnetic regions and not with unipolar (AP or AN) magnetic regions. Since

19

TABLE III

DISTRIBUTION OF MAGNETIC REGIONS AND SUNSPOT GROUPS ACCORDING TO CLASSIFICATION

AUG-1959 - DEC-1962

Magnetic Region Classification	AP	AN	B	BY	BS	BYS	Y	RB	RBY	RBS	RBYS	X
No. of Regions	431	317	761	44	28	10	24	49	4	2	0	458
Corresponding Sunspot Group Classification	-	-	$\alpha+$ $\beta_\circ$ $\alpha-$		$\beta\gamma$		γ	$r\beta$	$r\beta\gamma$			x
No. of Groups	212	653	88		23		10	0	0			83

unipolar magnetic regions are usually very weak, they are not associated
with any classification of sunspot group. Even small sunspots represent
relatively strong magnetic fields.

It was shown by Bell and Glaser (1959) that complex sunspot groups (BY
and Y) are associated with a larger ratio of major flares per group
than are bipolar or unipolar sunspot groups. Unipolar sunspot groups
are associated with very few major flares. Because of these known
associations and the sunspot group and magnetic region associations in-
dicated in Table III, it was anticipated that complex magnetic regions
(BY, BS, BYS, and Y) should also be associated with a greater ratio of
major flares per region than are the simple bipolar,(B) regions. Figure
9 shows this to be the case, except for the most complex class, Y.

3.3 Distributions of Magnetic Regions by Latitude

In Figure 8 five groups of magnetic regions are distributed in 2
degree increments by latitude. These groups are unipolar regions (AN,
AP), simple bipolar regions (B), complex bipolar regions (BS, BY, BYS),
reversed polarity simple bipolar regions (RB), and reversed polarity
complex bipolar regions (RBS, RBY, RBYS). The simple bipolar regions
and the complex bipolar regions show the well known distribution
pattern of active solar centers as a whole for this particular period
during solar cycle 19, August 1959-December 1962. The unipolar regions
are more evenly spread in latitude but still reflect the bipolar re-
gion pattern. This should be expected since they are the product of
aged bipolar regions, (Leighton, 1964; Smith and Howard, 1965). The
reversed polarity simple bipolar regions are the only group which has
a unique distribution centered around the solar equator and occurring
less frequently at higher latitudes. It appears that the equatorial
tail of the distribution curve for each polarity configuration in each
hemisphere overlaps the solar equator. The complex reversed polarity

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21
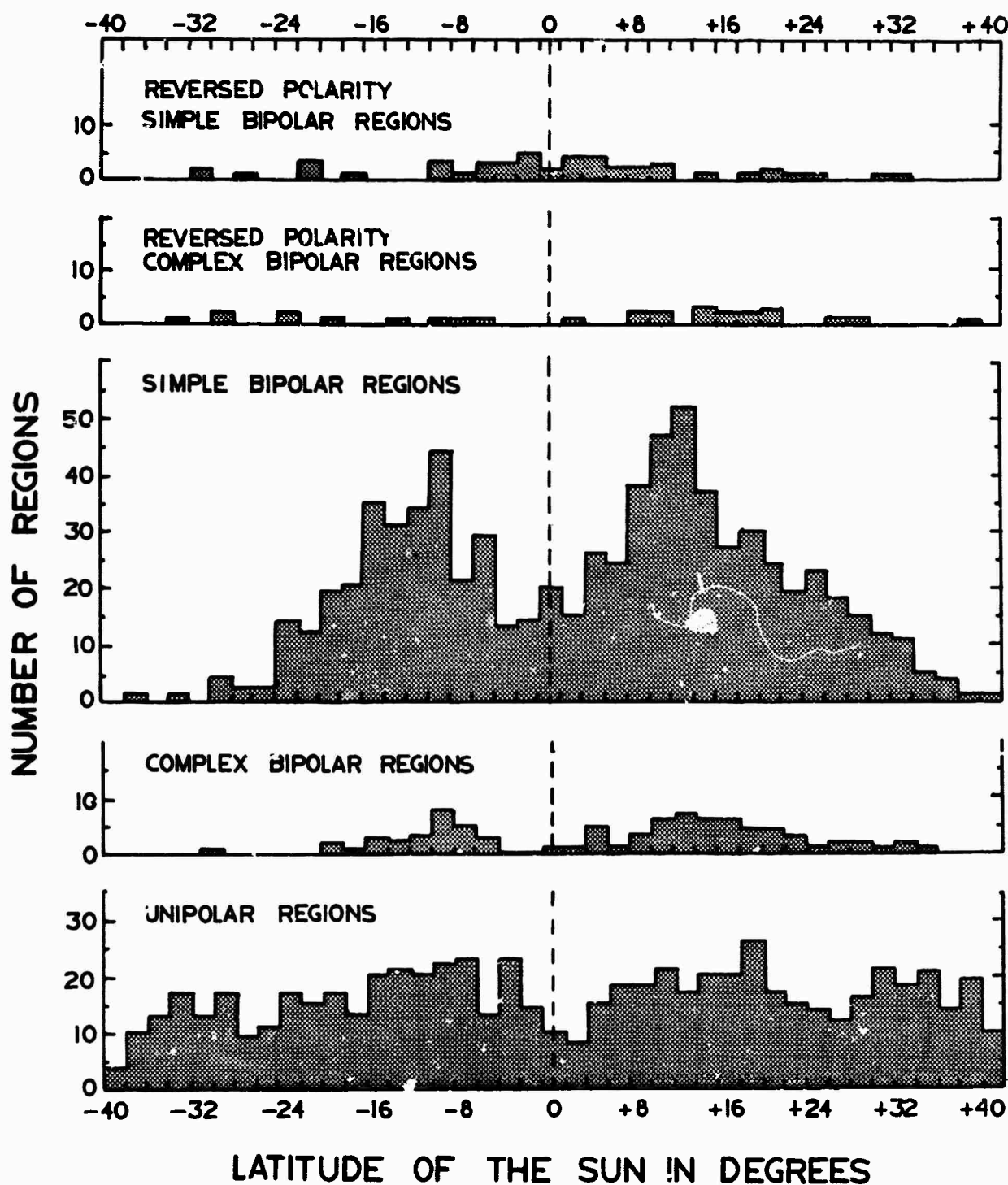
Figure 8. Distribution of Magnetic Regions by Latitude on the Sun, Aug. 1959-Dec. 1962. Reversed polarity simple bipolar regions are the only class of magnetic regions which tend to occur most frequently within 10° of the solar equator.

regions are too few in number to show a clear distribution pattern. This group can probably be best interpreted as sharing the distribution of the reversed polarity simple bipolar regions but which do not become complex except in the zone where the density of all magnetic regions is highest.

It is proposed that complex regions arise only when new regions, by chance, form in the midst of older regions or when two or more regions, by chance, are very close spaced. Additional studies should be designed to clarify whether or not this is an adequate explanation for the occurrence of complex magnetic regions on the sun.

3.4 A Distribution of Flares by Importance and Magnetic Region Classification

Table IV displays the number of flares associated with each class of magnetic region for a given flare importance rating. The total number of regions in each class are tabulated in the first column adjacent to the classifications. The flares in Table IV have been divided by the total number of regions of a given class and graphically illustrated in Figure 9 "Flare Productivity Per Magnetic Class". Considering flares of importance 1-, 1 and 1+, 2 and 2+, it is seen that all of the complex bipolar classes (BY+RBY, BS+RBYS, BYS+RBYS) are from 3 to 8 times as flare productive as the simple bipolar regions (B,RB). For flares of importance 3 and 3+, the complex bipolar classes (BY+RBY, BS+RBS) are more than 9 times as flare-productive as the simple bipolar regions. An unexpected result, however, appears for the most complex magnetic class, Y. This class is slightly less flare-productive than the simple bipolar regions. This result was not anticipated since the corresponding sunspot class (Y) is associated with a larger percentage of flares than any other class of sunspot group (Bell and Glazer, 1959).

TABLE IV

DISTRIBUTION OF FLARES BY IMPORTANCE AND MAGNETIC CLASS OF PLAGE

CLASS	NO. OF REGIONS	1-	1	1+	2	2+	3	3 +	TOTAL FLARES
X	(458)	411	963	122	75	10	13	2	1596
AP,AN	(748)	72	200	17	10	2	2	0	303
B	(761)	759	1732	202	141	1	18	2	2875
BY	(44)	166	378	47	22	8	7	2	630
BS	(28)	73	200	27	27	8	5	1	341
BYS	(10)	72	108	12	13	3	0	0	208
RB	(43)	10	45	4	4	1	0	0	64
RBY	(4)	5	13	1	0	0	0	0	19
RBS	(2)	6	16	1	0	1	1	0	25
RBYS	(0)	0	0	0	0	0	0	0	0
Y	(24)	27	45	4	0	1	1	0	78
	2128								

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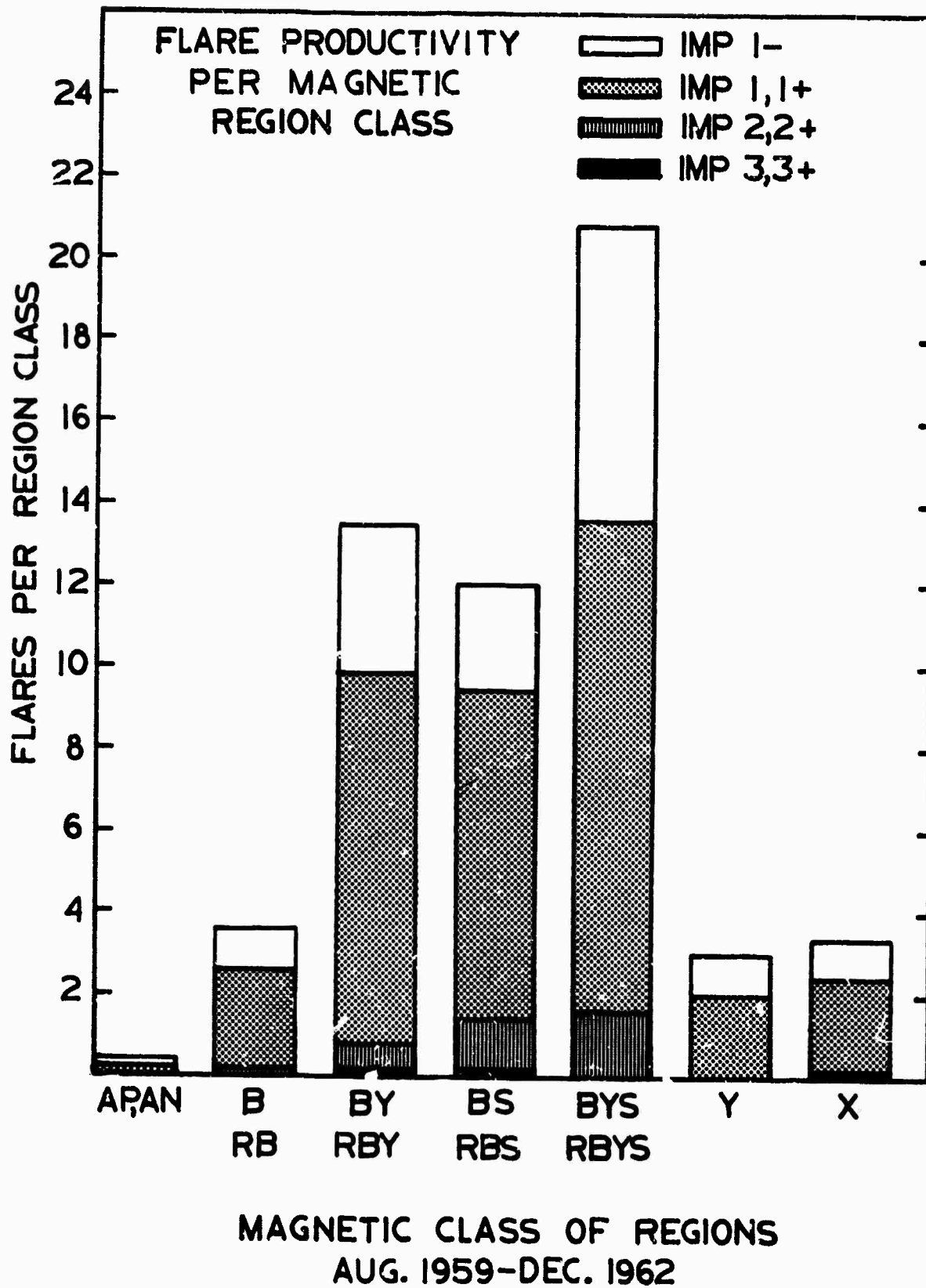
Figure 9. The Most Flare-productive Classes are Also the Most Complex Bipolar Magnetic Regions. The Most Complex Class, Y, However, Appears to be no More Flare-productive than the Simple Bipolar Regions.

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Section 4

MAGNETIC FIELD CHARACTERISTICS OF ACTIVE CENTERS
WHICH PRODUCED MAJOR FLARES

4.1 Statistics on Flare-productive Magnetic Regions

During the period August 1959 through December 1962, there were 24
active centers on the sun in which 3 or more major flares occurred
during one solar rotation. For this study we define a flare as major
if it was listed as $\geq$ importance 2 in Standardized Solar Flare Data
by C. S. Warwick (1966). These 24 flare-productive active centers
were chosen for detailed study of their magnetic field characteristics.
Twenty-four of the longest-lived or largest active centers occurring
during the same period which produced no major flares were selected
for a comparison sample. For the purposes of this part of the study
we consider two groups of magnetic region classifications: simple
bipolar regions (B,RB) and complex bipolar regions (BY, BS, BYS, RBY,
RBS, RBYS). The complex grouping includes any region that has a more
complicated configuration than a simple bipolar region. Even in the
most complex regions, however, basic bipolar configurations are al-
most always recognizable.

For clarity in the descriptive material the following definitions are
used:

   region - a magnetic entity, usually basically bipolar

   active center - general term referring to both the bright plage
           and surrounding area in chromospheric pictures
           which corresponds to one or more magnetic regions.

   plage - the part of an active center which appears as emission
           against the normal solar background.

All regions appearing on the visible solar hemisphere from August
1959 through December 1962 were initially assigned an average mag-
netic classification for the 13 days that each region was visible
during each solar rotation. According to the above groupings, there
were 810 simple bipolar regions, 112 complex bipolar regions, and
458 regions not classified because of poor quality data. Of the 24
most flare-productive active centers considered here only 3 were
simple bipolar regions, 8 were complex bipolar regions, and 2 were
unclassified regions. The remaining 11 were double or triple magnetic
regions of varying degrees of complexity; that is, 2 or 3 regions,
either simple or complex, which were very closely spaced.

For each day that data was available, the magnetic regions corres-
ponding to the 24 most flare-productive active centers were examined
for day to day changes in the general configuration of polarities.
It became apparent that average magnetic classifications for 13 day
periods are not adequate for meaningful comparisons with flare-pro-
ductivity. Also, the original method of classifying the regions did
not take into account the complexities which can arise in double or
triple magnetic regions.

The examination of individual regions revealed that 22 or the 24 most
flare-productive active centers were either complex or multiple re-
gions at some time during the 13 day periods of greatest productivity
of major flares. In 5 of the complex or multiple regions, a second
or third bipolar component made its first appearance on the disk.
In 7 other cases, the regions appeared to become more complex due to
the growth of a new polarity or the shifting of at least one of the
polarities in the regions. Seven cases were complex when first seen
crossing the east limb but did not appear to become magnetically more
complex. The data was too poor in the remaining 3 complex regions to
establish whether or not any significant new magnetic change had taken
place.

The 24 active centers which produced no major flares $\geq$ importance 2 tended to be more isolated from other regions and contained a much lower percentage of complex regions. In this sample of less flare-productive active centers, 11 were simple bipolar regions, 6 were not classified, 5 were complex bipolar regions, and only 2 were double bipolar regions.

A thorough examination of the life histories of these active centers in H-alpha was made and compared with the life histories of the group which did not produce any major flares. Ninety-two percent of all 48 active centers as observed in H-alpha had identifiable lifetimes of 3 rotations or less. The other eight percent, all of which were active centers which had produced 3 or more major flares, had lifetimes of 4 rotations. In the entire period from which these 48 active centers were selected, August 1959 through December 1962, no plage was found to have an identifiable lifetime of more than 4 rotations in H-alpha. By the 5th rotation, either a new active center had formed or, more often, the plage was beyond recognition as a definite entity.

Of the 24 active centers which produced major flares, 2 had plage lifetimes of 1 rotation; 10, 2 rotations; 9, 3 rotations; 4, 4 rotations. Of the 24 longest-lived or largest active centers which produced no major flares, 5 had a plage lifetime of 1 rotation; 14, 2 rotations; 5, 3 rotations.

It is thus clear that some of the most flare-productive active centers also have the longest-lived plage in H-alpha. For these samples, the flare-productive active centers generally tend to be longer-lived than the less flare-productive active centers. This may not be a significant result, however, since the less flare-productive samples are distributed later in the solar cycle when all active centers tend to be

shorter-lived.

The active centers which produced no major flares, in general, were not as large as the flare-productive sample. This difference in size again may be due in part to the later distribution of these active centers in the solar cycle and also to the fact that only 2 of these active centers were double bipolar regions.

The rotations in which 3 or more flares were produced were early in the life of the active centers; 20 of these flare-productive active centers had existed for less than one rotation ($<$ 27 days) and 4 less than two rotations. This suggests that flare productivity and magnetic region complexity may be related to the local conditions under which a region forms.

This relation of major flare incidence to plage age is definitely different then that found by H. J. Smith (1963) for IGY flares. Among the IGY flares, the majority of great flares (importance 3 or 3+) were reported as occurring in the second, third or fourth rotations of the active centers. The difference is probably due to our reclassification of plages which largely eliminates the many cases which, as stated by H. J. Smith (1963), "seem to undergo fusion or fission, as most long-lived regions do".

In H-alpha, all of the 24 flare-productive active centers were associated with the day to day appearance of additional bright plage sometime during the 13 day period of greatest flare productivity. On the average, additional plage appeared on at least 3 days per rotation. The positions at which new plage formed did not appear to follow any consistent pattern relative to the existing plage. Similarly, the development of magnetic complexities did not appear to follow a consistent pattern with respect to the existing magnetic field configuration.

It was found early in this study that a modified system of cataloguing active centers was essential to further work in this area. Therefore, all active centers observed from July 1959 through December 1962 were reclassified. This made studying the regions in question easier and eliminated most of the ambiguities which had resulted from trying to compare the McMath-Hulbert lists of plages with corresponding magnetic regions. The modified system attempts to more adequately account for the formation of new regions in old plage. The importance of having an improved system providing for this is reflected in the fact over half of the regions studied were formed in or near old plage. The evidence presented in this report indicates that these active centers are more likely to be the producers of numerous large flares.

For further studies of the flare-productivity of active centers, it is recommended that a program should be initiated to analyze and re-catalogue all active centers observed for the last solar cycle and eventually for the last 4 or 5 solar cycles. The final system of cataloguing should be designed to be compatible with computer pro-gramming and flexible enough to incorporate the results of better data.

4.2 Descriptions of Some Flare-productive Magnetic Field Configu-rations

Several interesting types of changes have been noted to precede or coincide with the flare-productive stage of magnetic regions. The most flare-productive region included in the previous section was a situation in which a reversed polarity simple bipolar region evolved into two normal bipolar regions. This slow evolution took place over a period of four solar rotations. In Figure 10, a series of magneto-grams show this unusual change. This region was also the only re-gion in the sample which produced 3 (or more) flares during more than one solar rotation. Fourteen of its flares of importance $\geq$ 2 occurred

during its first rotation and 3 more occurred during its second rotation. The rapid increase in complexity during the first rotation of this region is illustrated in the upper half of Figure 10. The isogauss contours in Figure 10, from outer to inner, represent mean magnetic field strengths of approximately 2, 6, 15 and 45 gauss except in the last three maps in which the 2 gauss levels is missing. New polarities appear on at least three successive days. During the next three rotations fewer good quality magnetograms were obtained and real day to day changes could not be ascertained. Large changes, however, are evident from rotation to rotation as is illustrated by the magnetograms in the lower half of Figure 10. Ageing of the region is evident from its increased area. By the fourth rotation, the region has evolved into two bipolar components, each of normal configuration for the northern hemisphere during solar cycle 19.

In Figure 11 are shown the magnetic field configurations also responsible for the production of more than 5 major flares during the first rotation of a region. From outer to inner, the isogauss contours represent field strengths of approximately 6, 15, and 45 gauss. The region in the upper left of Figure 11 was already strong when the first magnetogram was obtained on 28 November 1959 after it crossed the east limb. A small area of opposite polarity is seen in both the negative and positive polarity of the region. The growth of the new negative polarity in the positive component was accompanied by several major flares centering around the isolated polarity. A total of 14 major flares occurred in this region during the rotation illustrated.

A double bipolar configuration is shown in the upper right of Figure 11. This combination of regions produced 14 major flares during the rotation illustrated. With this resolution, 23 sec. of arc, the following polarities of each bipolar component appear to be connected.

Figure 10. Evolution of a Flare-productive, Reversed Polarity Magnetic Region. From Outer to Inner, the Isogauss Contours Represent Field Strengths of ~ 2, 6, 15 and 45 Gauss Except in the Last 3 Maps in Which the 2 Gauss Level is Missing.

However, the strongest interaction between the two bipolar components probably occurs between the following polarity of the lower lattitude region and the leading polarity of the higher latitude r gion.

Another example of the interaction of the following polarity of a new bipolar magnetic region with the leading polarity of an older bipolar region is shown in the lower left of Figure 14. In this case, the new region grew very close to the west of the old region and at approximately the same latitude. This process apparently resulted in the division of the following polarity of the new region into two units. Most of the 10 major flares in this complex, occur adjacent to the lines of polarity change formed by these separated units.

An almost simple bipolar region which produced 7 major flares is displayed in the lower right of Figure 11. The configuration shown is classed as complex, BY. On the previous day, two very small bipolar regions appeared at this location. On the following days, however, the region appears to become and remain a simple bipolar region.

Only one other region during the period August 1959 through December 1962 produced more than 5 known major flares during a single solar rotation. This region, which produced 8 major flares, crossed the central meridian of the sun on 26 June 1960 in the northern hemisphere. On 22 June it was a simple bipolar region. On 30 June, however, a new bipolar region appears to be centered approximately 6 degrees south and 5 degrees west of the center of the original region. This unusual close spacing of regions strongly suggests that this is another situation in which a new region forms and interacts with an older well developed region. The magnetograms on the intervening days are of insufficient quality to determine additional information about the magnetic field changes occurring in this flare-productive situation.

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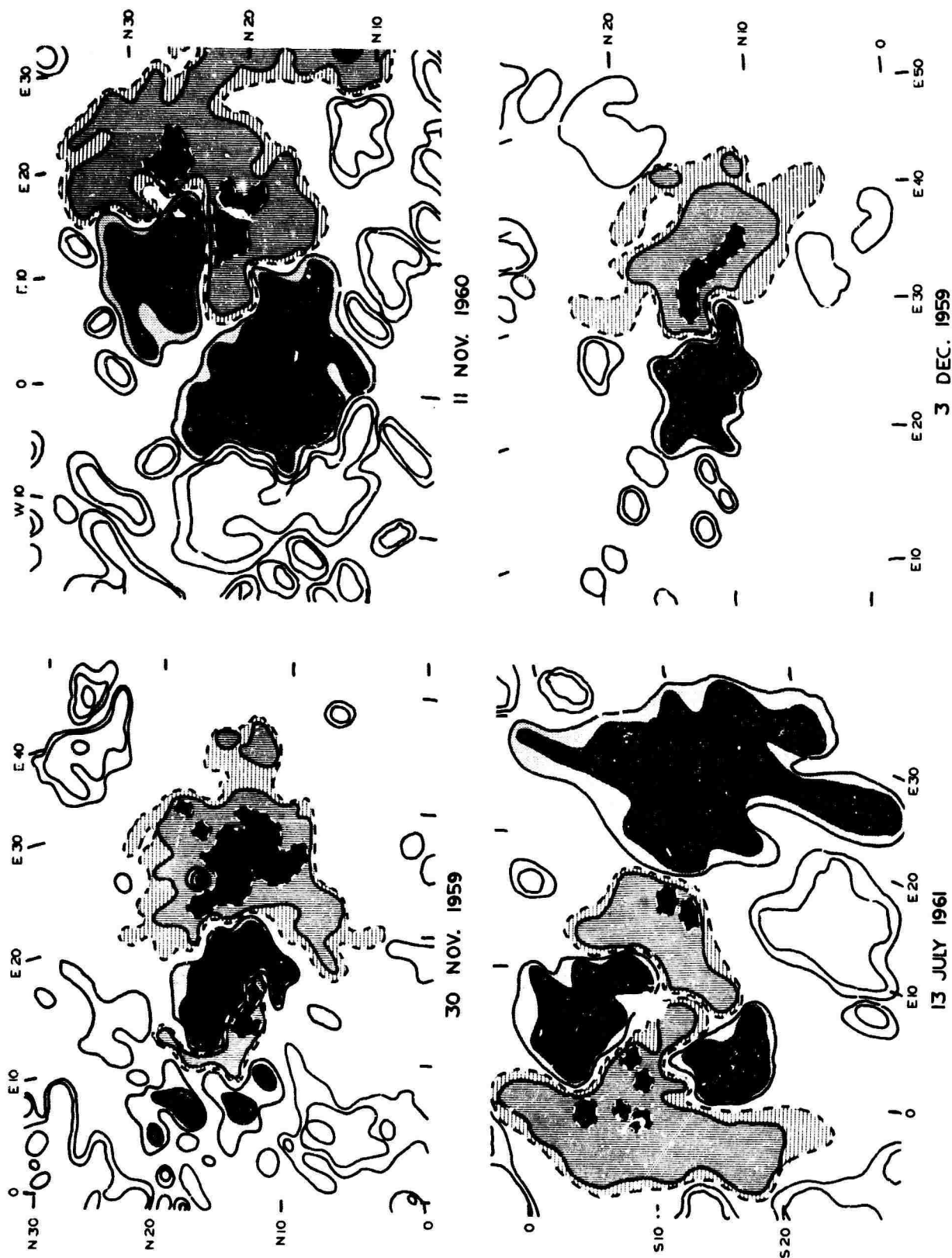
Figure 11. Upper Left: A Region with an Isolated Polarity in Both the Positive and Negative Bipolar Components. Upper Right: A Double Bipolar Configuration Aligned in a North-South Direction. Lower Left: A Double Bipolar Configuration Aligned East-West; Positive Polarity of Leading Region is Split into Two Components. Lower Right: An Almost Simple Bipolar Region. BY Configuration. From Outer to Inner, the Isogauss Lines Represent Field Strengths of 6, 15, and 45 Gauss.

Section 5

SUMMARY AND RECOMMENDATIONS

The shape, size, and intensity of chromospheric fine structures are
found to be related to the strength of the longitudinal component of
a photospheric magnetic field. Additional evidence is illustrated
showing that initial flare positions occur adjacent to neutral lines
or lines of 0 longitudinal field strength and that flare emission
drifts approximately perpendicular to and away from neutral lines.
The velocity and deceleration of the flare drift for one event are
shown to be related to the strength of the longitudinal component of
the photospheric magnetic field.

Complex bipolar regions proved to be statistically over 3 times as
flare-productive as simple bipolar regions. Evidence that flare
productivity is directly related to magnetic field complexity also
resulted from a detailed study of a sample or the most flare-pro-
ductive regions and a comparable sample of the longest-lived and
largest but less flare-productive regions. Magnetic complexity, in
turn, appeared to be related to the conditions under which regions
develop, particularly in or near older regions. For most of the
complex regions, the greatest number of major flares occurred during
the first solar rotation that new magnetic field components developed
either in or near the regions. It appeared that flares can be pro-
duced as a result of the interaction of two or more closely spaced
bipolar regions. These results suggest that further study of the
evolution of regions as complexes of activity should be very profit-
able.

The distribution of reversed polarity simple bipolar regions is shown

to be different than for active centers which are either simple or complex bipolar regions. Reversed polarity regions are relatively few in number and tend to occur less frequently with increasing distance from the solar equator.

It is evident from this study that improved systems for classifying plages and magnetic regions need to be devised. It is recommended that further statistical analysis of this data be postponed until a revision of the magnetic region classifications has been made. Due to the inconsistency in quality in most of the magnetic region data during this period (Aug. 1959-Dec. 1962) a review of the corresponding plages is advisable.

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Unclassified

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13.   ABSTRACT(Continued)

consequence of unusually close spacing.

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DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY *(Corporate author)*	2a. REPORT SECURITY CLASSIFICATION
Lockheed-California Company P.O.Box 551, Burbank, California	Unclassified
	2b. GROUP

3. REPORT TITLE

FINAL REPORT-SOLAR MAGNETIC FIELDS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final Report-Period Covered: 21 March 1966 - 30 Nov. 1966

5. AUTHOR(S) *(Last name, first name, initial)*

Smith, Sara F.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
	45	10

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
Contract No. N-00014-66-C0058	LR-20445
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

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13. ABSTRACT

Optical and magnetic field records of high resolution were obtained on 6 July 1965. These observations reveal an excellent correlation between the size, shape, and intensity of the H-alpha fine structures and the longitudinal component of the photospheric magnetic fields, except in the vicinity of the neutral line. Sections of the neutral line are marked by long fibrils running perpendicular to the neutral line or by small filaments paralleling the neutral line.

The development of a major flare in this region appeared to be more precisely related to the neutral line than was found for the flares and magnetic fields observed with lower resolution. The 2 major segments of this flare lengthened in directions approximately parallel to the neutral line while simultaneously drifting perpendicularly away from the neutral line. The rate of drift systematically varied from 1 to 12 km/sec. with increasing distance from strong fields. The rate of drift was also observed to decelerate throughout the life of the flare.

A comparison of the distribution of various classes of magnetic regions shows that reversed polarity regions are relatively rare and tend to cluster around the solar equator. Complex bipolar regions occur most frequently at those latitudes where the density of all regions is highest. The ratio of complex bipolar to simple bipolar regions for the period studied was approximately 1:9. However, the complex bipolar regions were at least 3 times as flare-productive as the simple bipolar regions. Flare-productive complex magnetic field configurations may result when new regions form in older regions or when 2 or more regions appear to interact as a

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14 KEY WORDS	LINK A		LINK B		LINK C	
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